California Air Resources Board

Greenhouse Gas Quantification Methodology for the California Department of Food and Agriculture Dairy Digester Research and Development Program

Greenhouse Gas Reduction Fund
Fiscal Year 2016-17

May 2, 2017

Note:
This DDRDP GHG quantification methodology and accompanying GHG Calculator Tool were originally posted on March 16, 2017. No changes were made to the quantification methodology; however, the GHG Calculator Tool was updated with a minor correction to the energy-corrected milk calculation. Applicants must use the May 2, 2017 versions of the DDRDP GHG quantification methodology and accompanying GHG Calculator Tool.

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Section A. Introduction

The goal of California Climate Investments is to reduce greenhouse gas (GHG) emissions and further the purposes of the Global Warming Solutions Act of 2006, known as Assembly Bill (AB) 32. The California Air Resources Board (ARB or Board) is responsible for providing the quantification methodology to estimate the net GHG emission reductions and other benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). ARB develops these methodologies based on the project types eligible for funding by each administering agency as reflected in the program Expenditure Records available at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/expenditurerecords.htm. ARB staff periodically reviews each quantification methodology to evaluate its effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified.

For the California Department of Food and Agriculture's (CDFA) Dairy Digester Research and Development Program (DDRDP), ARB staff developed this quantification methodology and DDRDP GHG Calculator Tool to provide methods for estimating net GHG emission reductions of each proposed project (Section B), provide instructions for documenting and supporting the estimate (Section C), and outline the process for tracking and reporting GHG and other benefits once a project is funded (Section D).

This methodology calculates GHG emission reductions to be achieved through the installation of a biogas control system (BCS), commonly referred to as a dairy digester, which captures and utilizes biogas produced by the anaerobic decomposition of livestock manure and/or other organic material. Projects will report the total project GHG emission reductions over the project life estimated using this methodology, the total project GHG emission reductions per unit of energy-corrected milk production, and the total project GHG emission reductions per dollar of GGRF funds requested.

DDRDP Project Types

DDRDP supports several project types for which there are methods to quantify GHG emission reductions. Each DDRDP project requesting GGRF funding must include at least one of the following project components for FY 2016-17:

- BCS that utilizes recovered biogas for electricity generation;
- BCS that recovers biogas and upgrades to biomethane for use as transportation fuel, whether onsite, at a nearby facility, or through pipeline injection;
- BCS that recovers biogas for combustion in a boiler that utilizes thermal energy in a process thereby reducing demand for fossil-fuel based energy in that process.

Manure management projects that do not include the installation of a BCS may be eligible for funding under the Alternative Manure Management Practices Program also administered by CDFA.

Section B provides the methods to use based on the project component(s) proposed.

Methodology Development

ARB and CDFA developed this quantification methodology through a public process consistent with the guiding implementation principles of California Climate Investments, including ensuring transparency and accountability.[i] This quantification methodology was developed to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology will:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven tools and methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

ARB, in consultation with CDFA, reviewed peer-reviewed literature and tools and consulted with experts as needed to determine methods appropriate for the DDRDP project types. The methods were developed to provide reliable estimates with data readily available to project proponents.

This quantification methodology is based on ARB's 2014 Compliance Offset Protocol for Livestock Projects (Livestock Protocol).[ii] The Livestock Protocol was initially adopted by the Board on October 20, 2011 for the purpose of ensuring the complete, consistent, transparent, accurate, and conservative quantification of the net GHG benefit associated with a livestock digester offset project in order to generate ARB offset credits for use in the Cap-and-Trade Program.[iii] An updated version of the Livestock Protocol was adopted by the Board on November 14, 2014.

While the Livestock Protocol is used to generate ARB offset credits based on measured data after implementation of a project, this quantification methodology is used to estimate the net GHG benefit of a project prior to project implementation in order to assist in awarding competitive GGRF grants. For this reason, this quantification methodology includes some simplifying assumptions due to the need to estimate emission reductions prior to implementation of a BCS project.

ARB developed the initial FY 2014-15 DDRDP quantification methodology[iv] based on a calculation of pre-project baseline GHG emissions, which represents the maximum potential GHG reductions that a BCS project may achieve. This updated FY 2016-17 quantification methodology includes several new features to more accurately estimate the net GHG benefit of BCS projects, and to better account for project-specific features.

Tools

Applicants must use this quantification methodology, in conjunction with the accompanying DDRDP GHG Calculator Tool, to estimate the net GHG emission reductions of the proposed project. The DDRDP GHG Calculator Tool can be downloaded from: www.arb.ca.gov/cci-quantification. Required inputs to the DDRDP GHG Calculator Tool are listed in Section B, Step 2. Instructions to use the tool are provided in Section B and an example project is included in Appendix A.

Major Updates

This quantification methodology uses emission calculation methodologies from the Livestock Protocol in order to allow DDRDP applicants to estimate a net GHG benefit prior to project implementation. The "baseline scenario" represents the GHG emissions that are presently occurring and that would occur in the absence of a DDRDP project. The previous version of this quantification methodology (FY 2014-15) used the baseline scenario to estimate potential reductions from implementing a DDRDP project. This represented the maximum possible emission reductions and assumed a 100% collection and destruction efficiency. Actual net project emission reductions will always be less than the baseline scenario due to factors such as methane (CH_4) capture and destruction inefficiencies, anaerobic decomposition of residual volatile solids not digested in the BCS, and potential periods of equipment malfunction.

ARB updated this quantification methodology from the previous version for FY 2016-17 to better account for project-specific features and to more accurately estimate GHG emission reductions. The updates are based on equations and default factors in the Livestock Protocol, but use estimated rather than measured values for the "project scenario" (i.e. for the calculation of GHG emissions after installation of a BCS). The major changes include:

- Inclusion of estimated residual methane emissions after installation of a BCS from:
    - Biogas collection inefficiencies;
    - Biogas destruction inefficiencies;
    - Volatile solids in uncovered effluent pond (when applicable);
    - Other non-BCS manure treatment/storage systems (when applicable);
- Calculation of GHG benefit associated with biogas end use, including:
    - Avoided GHG emissions associated with grid electricity when projects include electricity generation;

- Avoided GHG emissions associated with diesel fuel when biogas is upgraded to biomethane and used as transportation fuel, either onsite or through pipeline injection.
- Avoided GHG emissions associated with fossil natural gas when biogas is combusted in a boiler that utilizes thermal energy in a process that reduces demand for fossil-fuel based energy in that process.

Program Assistance

CDFA staff, along with the Technical Advisory Committee (TAC) – a sub-committee of the California-Federal Dairy Digester Working Group – and other technical experts as needed, will review the quantification portions of the DDRDP project applications to ensure that the methods described in this document have been properly applied to estimate the GHG emission reductions for a proposed project. Applicants should use the following resources for additional questions and comments:

- Questions on this document should be sent to GGRFProgram@arb.ca.gov.
- For more information on ARB's efforts to support implementation of GGRF investments, see: https://www.arb.ca.gov/auctionproceeds.
- Questions pertaining to the DDRDP should be sent to cdfa.oefi@cdfa.ca.gov.

Section B. GHG Quantification Methodology

Overview

This methodology estimates the net GHG benefit of a proposed DDRDP project based on avoided methane emissions from anaerobic manure decomposition. It also includes an estimation of the benefit for avoided CO_2 emissions associated with electricity generation in projects where a BCS will be used to generate electricity, with diesel fuel in projects where biogas is upgraded to biomethane for use as transportation fuel, and with fossil natural gas in projects where thermal energy from biogas combusted in a boiler is utilized in a process that reduces demand for fossil-fuel based energy in that process.

Methane production depends on the amount of manure produced, the fraction of volatile solids that decompose anaerobically (i.e., the biodegradable organic material in the manure), temperature, and the retention time of manure during treatment and storage. This methodology combines project-specific data with default factors to establish both a baseline scenario and a project scenario.

Net GHG emission reductions are calculated by subtracting estimated post-project GHG emissions from the uncontrolled baseline scenario emissions. Additional GHG emissions reductions are then added based on the end use of the captured biogas.

In general, the net GHG emission reductions are calculated using the following approaches:

Table 1. General Approach to GHG Quantification

BCS with Electricity Generation
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of electricity generation)
BCS with upgrade to Biomethane for use as Transportation Fuel (either onsite or through Pipeline Injection)
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of production of biomethane)
BCS with recovery of useful thermal energy from combustion of biogas in Boiler
Net Emission Reductions = (Baseline CH_4 and CO_2 emissions) – (Project CH_4 and CO_2 emissions) + (Additional GHG benefit of recovered thermal energy)

Applicants will follow the steps outlined in Figure 1 to estimate the net GHG emission reductions from the proposed project. Detailed instructions for each step are provided on subsequent pages.

Figure 1. Steps to Estimate Net GHG Emission Reductions

Step 1. Identify the Project Boundary

Step 2. Determine the DDRDP GHG Calculator Tool Inputs Needed

Step 3. Locate and Report the Net GHG Emission Reductions using the DDRDP GHG Calculator Tool

Step 1: Identify the Project Boundary

The project boundary delineates the GHG sources, sinks, and reservoirs (SSRs) that are included or excluded when quantifying the emission reductions resulting from the installation and operation of a device, or set of devices, associated with the capture and destruction of methane. The calculation procedure only incorporates methane and carbon dioxide; nitrous oxide emissions are not assessed.[1]

Table 2 lists the SSRs for DDRDP projects, indicating which gases are included or excluded from the project boundary for the purpose of this methodology.

[1] The IPCC notes that the nitrification of ammonia to nitrate is an essential prerequisite to the emission of N_2O from animal manures, and this process does not occur under anaerobic conditions. As a result, they assign an N_2O emission factor of 0 for direct N_2O emissions from both anaerobic lagoons and anaerobic digesters. Thus diverting manure from one anaerobic environment (lagoon) to another (BCS) is unlikely to significantly alter the N_2O profile of a dairy's manure management operations. *IPCC Guidelines for National Greenhouse Gas Inventories* (2006). Volume 4: Agriculture, Forestry and Other Land Use: Chapter 10: Emissions from Livestock and Manure Management. (10.52,10.62-10.63). http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

Table 2. Description of all SSRs

SSR	GHG Source	CO_2	CH_4
1	Emissions from enteric fermentation	Excluded	Excluded
2	Emissions from mobile and stationary support equipment*	Included	Excluded
3	Emissions from mechanical systems used to collect and transport waste (e.g. engines and pumps for flush systems; vacuums and tractors for scrape systems)*	Included	Excluded
	Vehicle emissions (e.g. for centralized digesters)*	Included	Excluded
4	Emissions from waste treatment and storage including: anaerobic lagoons, dry lot deposits, compost piles, solid storage piles, manure settling basins, aerobic treatment, storage ponds, etc.	Excluded	Included
	Emissions from support equipment*	Included	Excluded
5	Emissions from the anaerobic digester due to biogas collection inefficiencies and venting events	Excluded	Included
6	Emissions from the effluent pond	Excluded	Included
7	Vehicle emissions for land application and/or off-site transport*	Included	Excluded
8	Emissions from combustion during flaring, including emissions from incomplete combustion of biogas	Excluded	Included
9	Emissions from combustion during electric generation, including incomplete combustion of biogas	Excluded	Included
10	Emissions from equipment upgrading biogas for pipeline injection or use as transportation fuel*	Included	Excluded
11	Emissions from combustion of biogas at boiler including emissions from incomplete combustion	Excluded	Included
12	Emissions or emission reductions from combustion of biogas by end user of pipeline biomethane or biomethane transportation fuel	**Included	Included
13	Emission reductions associated with delivery and use of project electricity to grid	***Included	Excluded
14	Off-site thermal energy or power	Excluded	Excluded
15	Use of project-generated thermal energy	****Included	Excluded
16	Project construction and decommissioning emissions	Excluded	Excluded

* Carbon dioxide emissions associated with the baseline or project scenario include, but are not limited to, the following sources: electricity use by pumps and equipment, fossil fuel generators used to destroy biogas; power pumping systems; milking parlor equipment; flares; tractors that operate in barns or freestalls; on-site manure hauling trucks; and vehicles that transport manure off-site.

** When biogas is upgraded to biomethane and used as transportation fuel onsite or through pipeline injection, the benefit of avoided diesel CO_2 emissions is calculated.

*** When a BCS uses biogas to generate electricity, a benefit associated with avoided fossil CO_2 emissions is also calculated based on a California grid-average emission factor.

**** When biogas is combusted in a boiler and recovered thermal energy is utilized in a non-BCS related process that reduces the demand for fossil-based energy, the benefit of avoided fossil natural gas CO_2 emissions is calculated.

Step 2: Determine the DDRDP GHG Calculator Tool Inputs Needed

Table 3 identifies the required data inputs needed to estimate the net GHG emission reductions for proposed projects with the DDRDP GHG Calculator Tool.

Table 3. Required DDRDP GHG Calculator Tool Inputs

General Information (Read Me worksheet) • Project Name; • Grant Application Pin #; • Contact Name; • Contact Phone Number; • Contact Email; and • Date Completed. **Project Information** • Type of BCS (i.e. covered lagoon, plug flow, complete mix or fixed film); • Primary biogas destruction device or end use (from drop-down list); • Secondary biogas destruction device or end use (if applicable); • Fraction of biogas to be destroyed in each destruction device over 10 years; • Type of solid-separation both before and after installation of the BCS (e.g. gravity, vibrating screen, etc.) selected from a drop-down list; • Presence of any uncovered effluent pond after installation of BCS; • Project location (County); • GGRF funds requested; • Specifications of milk produced (kg/day, % fat, % true protein,% lactose); • Number of livestock by category (dairy cows in freestalls, dairy cows in open lot corrals, dry cows, and heifers) based on average of preceding 12 months data; • % of manure volatile solids deposited on land and not collected (baseline and project scenario) for each livestock category; • % of volatile solids separated prior to entry into the anaerobic lagoon or BCS, and sent to another treatment/storage practice, and identification of that practice from a drop-down list for each livestock category (baseline and project scenario); • % of volatile solids sent to the anaerobic treatment/storage system in the baseline and sent to the BCS after installation; • Baseline electricity and fossil fuel consumption associated with manure management activities by fuel type (MWh/yr, gallons/yr, scf/yr, or MMBtu/yr); • Estimated electricity and fossil fuel consumption associated with manure management activities by fuel type (MWh/yr, gallons/yr, scf/yr, or MMBtu/yr) after installation of the BCS; • Descriptive list of stationary and mobile CO_2 emission sources associated with manure management activities.

Step 3: Estimate Net GHG Emission Reductions for the Proposed Project Using the DDRDP GHG Calculator Tool

Applicants must use the DDRDP GHG Calculator Tool to complete this step. The Calculator Tool can be downloaded from www.arb.ca.gov/cci-quantification.

Users should begin with the **Read Me** tab, which contains instructions and prompts users to enter project information. Key terms are defined in the **Definitions** tab. The **Project Data Inputs** tab identifies inputs required by the user. Input and output fields are color coded:

- **Yellow** fields indicate that a direct user input is required, or that a selection from a drop-down box is required.
- **Green** fields indicate that a direct user input is optional, as it will be applicable for some projects but not others. All applicants should review these fields to determine the applicability to their project.
- **Gray** fields indicate metrics calculated by the DDRDP GHG Calculator Tool and which may be included in the project application.

Some projects may have both a primary and a secondary biogas destruction device or end use. For example, a project that upgrades biogas to biomethane transportation fuel may also still utilize an engine for electricity generation onsite. In such cases, the project applicant will indicate both the primary and secondary destruction device/pathway in the tool, and estimate the % of biogas to be destroyed in each pathway over 10 years. Note: Selection of multiple biogas destruction devices or pathways in the tool must be consistent with all project design documentation. A project must not claim GHG benefits related to upgrading to biomethane for transportation fuel if this remains an aspirational goal at the time of project application; such a claim must be supported by all project planning documentation and concrete steps taken by project applicants.

Where default values are provided in the DDRDP GHG Calculator Tool, applicants should use these default values unless more accurate, site-specific information is available. However, when non-default values are used, applicants should submit documentation with their application justifying the use of site-specific values.

The DDRDP GHG Calculator Tool assists applicants in accounting for manure volatile solids in a step-by-step manner in both the baseline and project scenario.

Baseline Manure Management -- Enter data regarding management practices using averages of preceding 12 months								
	1. Enter number of livestock by category	2. Enter % of manure volatile solids (VS) deposited on land and not collected Default		3. Enter % VS from solid separation prior to lagoon sent to other treatment/storage practice Default		4. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	5. Enter % VS entering anaerobic storage/treatment system (lagoon) by livestock category	Total Volatile Solids must sum to 100%
Dairy Cows (freestall)	2,000	20%	20%	14%	14.0%		66.0%	100%
Dairy Cows (open lot corrals)		70%		17%				
Dry cows		70%		17%				
Heifers		70%		17%				
			Pasture / Dirt		Dried for bedding / Composting intensive windrow Identify current practice for separated solids	Identify other current treatment/storage practice		

- **Input 1**: Applicants enter the number of livestock by category based on the average of preceding 12 months data. These values are assumed to remain constant in both the baseline and project scenario.
- **Input 2**: Indicate the % of manure volatile solids dropped directly on land and not collected. This quantification methodology assumes default values of 20% for dairy cows housed in freestalls, and 70% for dairy cows housed in open-lot corrals, as well as for dry cows and heifers.[2]
- **Input 3**: Enter the % of manure volatile solids that are separated out prior to entry into the anaerobic lagoon (baseline scenario) or BCS (project scenario). Default values from Table C.8. (adjusted to account for input 2) are provided in the tool based on the solid separation technology, if any, identified by the applicant. Applicants also identify from a drop-down list how the separated solids will be treated or managed.
- **Input 4**: This optional input allows applicants to account for any other manure volatile solids that do not enter the anaerobic lagoon (baseline scenario) or BCS (project scenario). For example, if separated solids are sent to two different practices, one would be selected for input 3 and the other for input 4, with the fractions apportioned appropriately.
- **Input 5**: Enter the % of manure volatile solids that enter the anaerobic lagoon (baseline) or BCS (project scenario). This should be equal to 100% minus the values entered in inputs 2-4. If not, warning notice will appear in the tool.

Finally, applicants will input electricity and fossil fuel consumption by fuel type for both the baseline and project scenarios, and list all combustion sources individually at the bottom of the worksheet.

A detailed example of how to input project application data into the DDRDP GHG Calculator tool is contained in Appendix A. Details of calculation methods are provided in Appendix B.

The **GHG Summary** tab displays GHG emission reduction metrics as described below.

- **Total Project GHG Emission Reductions** is equal to the difference between annual baseline and project emissions, plus any applicable additional GHG benefit from biogas end use, summed over the 10 year project life.

[2] These were derived from the average time cows spend inside and outside of areas where manure solids may be collected/flushed, and are based on the median values of the ranges given in the UC Davis Division of Agriculture and Natural Resources Committee of Experts on Dairy Manure Management (2005) study *Managing Dairy Manure in the Central Valley of California*. (23-24). http://groundwater.ucdavis.edu/files/136450.pdf.

- **Total Project GHG Emission Reductions per Dollar of DDRDP GGRF funds requested** is calculated as:

$$\frac{Total\ Project\ GHG\ Emission\ Reductions\ in\ Metric\ Tons\ of\ CO_2e}{DDRDP\ GGRF\ Funds\ Requested\ (\$)}$$

  Applicants should enter the DDRDP GGRF Funds Requested ($) for all project features into the **Project Data Inputs** tab of the DDRDP GHG Calculator Tool. This amount is equal to the amount of GGRF dollars the applicant is requesting from CDFA's Dairy Digester Research and Development Program.

- **Total Project GHG Emission Reductions per Dollar of Total GGRF funds requested** is calculated as:

$$\frac{Total\ Project\ GHG\ Emission\ Reductions\ in\ Metric\ Tons\ of\ CO_2e}{Total\ GGRF\ Funds\ Requested\ (\$)}$$

  Applicants should enter the Total GGRF Funds Requested ($) into the **Project Data Inputs** tab of the DDRDP GHG Calculator Tool. This amount is equal to the amount of GGRF dollars the applicant is requesting from CDFA's Dairy Digester Research and Development Program, plus any other GGRF dollars received or requested for other projects at same project location. Include funds that have previously been awarded to the same project (if applicable) and any GGRF dollars that the project has or plans to apply for (if applicable). For a list of GGRF funded programs, go to: www.arb.ca.gov/cci-events. If no other GGRF funds are requested, this will be the same amount as the DDRDP GGRF Funds Requested.

- **Total Project GHG Emission Reductions per kg of energy-corrected milk production** is calculated as:

$$\frac{Total\ Project\ GHG\ Emission\ Reductions\ in\ Metric\ Tons\ of\ CO_2e}{Energy\ Corrected\ Milk\ Production\ (ECM) in\ metric\ tons}$$

  This metric is intended to be used as a selection criteria by CDFA in the application scoring process. Milk production characteristics from the **Project Data Inputs** tab are used to calculate energy-corrected milk. Using an energy-corrected milk production metric helps to account for differences in milk production rates and cow breeds among dairies.

Section C. Documentation

In addition to DDRDP application requirements, applicants for GGRF funding are required to document results from the implementation of a BCS project in accordance with this quantification methodology, including supporting materials to verify the accuracy of project-specific inputs.

Applicants are required to provide electronic documentation that is complete and sufficient to allow the calculations to be reviewed and replicated. Paper copies of supporting materials must be available upon request by CDFA staff.

The following checklist is provided as a guide to applicants; additional data and/or information may be necessary to support project-specific input assumptions.

	Documentation Description	**Completed**
1.	Project description, including excerpts or specific references to the location in the main DDRDP application of the project information necessary to complete the applicable portions of the quantification methodology.	
2.	Populated DDRDP GHG Calculator Tool file (in .xlsx) with worksheets applicable to the project populated (ensure that all Yellow fields in the ‘Project Data Inputs’ worksheet are completed and all Gray fields in the ‘GHG Summary’ worksheet contain calculated values).	
3.	If the Total GGRF Funds Requested are different than the DDRDP GGRF Funds Requested, identify the other GGRF program(s) where funding is sought, including the date of the application(s).	
4.	Information necessary and appropriate to substantiate inputs (e.g., documentation of baseline livestock population, fossil fuel and electricity consumption, specifications of BCS design, relevant environmental permits, etc.) must be kept onsite and made available to CDFA or ARB upon request.	

Section D. Reporting after Funding Award

Accountability and transparency are essential elements for all GGRF California Climate Investment projects. As described in ARB's Funding Guidelines for Agencies that Administer California Climate Investments (Funding Guidelines),[v] each administering agency is required to track and report on the benefits of the California Climate Investments funded under their program(s). Each project funded by the GGRF is expected to provide real and quantifiable GHG emission reductions. The previous sections of this document provide the methods and tools to estimate the GHG emission reductions of a proposed project based on project characteristics and assumptions of expected conditions and activity levels. This section explains the minimum reporting requirements for administering agencies and funding recipients during project implementation, termed Phase 1, and after a project is completed, termed Phase 2. Table 4 below shows the project phases and when reporting is required.

Table 4. Quantification and Reporting By Project Phase

	Timeframe & Reporting Frequency	Quantification Methods
Project Selection	Period from solicitation to selection of projects and funding awards. Applicant submits application to CDFA by due date in solicitation materials.	All applicants use methods in ARB's quantification methodology to estimate the GHG emission reductions of the project.
Phase 1	Period from project award date through project completion date. CDFA reports to ARB on an annual basis.	All awarded projects use methods in ARB's quantification methodology to update initial estimate of GHG emission reductions, as needed, based on project changes.
Phase 2	Begins after project completion. CDFA reports to ARB consistent with the Funding Guidelines.	GHG reduction estimates are updated and reported for all awarded projects.

Funding recipients have the obligation to provide, or provide access to, data and information on project outcomes to CDFA. Applicants should familiarize themselves with the requirements below as well as those within the DDRDP solicitation materials (e.g., guidelines, applications, etc.), and grant agreement.

It is the responsibility of administering agencies to collect and compile project data from funding recipients, including net GHG emission reductions and information on benefits to disadvantaged communities.

Phase 1 reporting is required for all DDRDP projects. CDFA will collect and submit data to ARB to satisfy Phase 1 reporting requirements. Projects must report any changes that impact net GHG emission reduction estimates (i.e., assumptions or quantities) to CDFA prior to project completion.

Phase 2 reporting is also required for all DDRDP projects and is intended to document actual project benefits achieved after a project becomes operational. CDFA will be responsible for collecting Phase 2 data and for reporting the required information to ARB. ARB will work with CDFA to address Phase 2 procedures, including but not limited to:

- The **timelines** for Phase 2 reporting, i.e., when does Phase 2 reporting begin, how long will Phase 2 reporting be needed.
- **Methods for monitoring or measuring** the necessary data to quantify and document achieved GHG reductions and other select project benefits.
- **Data to be collected**, including data fields needed to support quantification of GHG emission benefits.
- Reporting requirements for transmitting the data to ARB or CDFA for program transparency and use in reports.

Once the Phase 2 quantification method and data needs are determined, ARB will develop and post the final ARB approved Phase 2 methodology for use in Phase 2 reporting.

Appendix A. Example Project

Introduction

The following is an example project to demonstrate how the FY 2016-17 DDRDP Quantification Methodology would be applied. This example does not provide examples of the supporting documentation that is required of actual project applicants.

Overview of the proposed project

The proposed project is requesting $2 million dollars from DDRDP for a BCS that utilizes recovered biogas for electricity generation proposing the following components:

- Covered lagoon BCS design;
- Biogas utilized for electricity generation with rich-burn internal combustion (IC) engine.
- Solid separation via stationary screen;
  - Half of separated solids is dried and used for bedding while the other half is applied directly to land each day (daily spread);
  - Fraction of volatile solids separated is not measured, so default values are used;
- Uncovered effluent pond;
- Located in Kern County;
- $2,000,000 requested from GGRF;
- 2,000 freestall lactating dairy cows, 200 dry cows, and 300 heifers;
- Average milk production of 25 kg/cow/day, with 3.75% milk fat, 3% true protein, and 4.9% lactose;
- All manure sent to anaerobic lagoon in the baseline and to the BCS in the project case, except for separated solids and what is deposited on land in areas where it is not collected;
- 500 gallons of diesel fuel used for manure management support equipment in baseline and project scenarios (support equipment emissions unchanged);
- 500 MWh electricity consumption in baseline scenario and 600 MWh estimated for project scenario (increase associated with electricity use by stirrers in digester and other BCS support equipment);
- Propane pilot light of IC-engine identified as new combustion source, estimated 30 gallons/yr.

Methods to apply

Step 1: Identify the Project Boundary

The first step in quantifying this example project is to determine the Project Boundary. In order to do this, the applicant should review included sources in Table 2 as it relates to their dairy operations. Applicants must be sure to identify any combustion sources associated with manure management operations prior to the installation of a BCS, identify how these emissions are expected to change as a result of the project, and identify if the project includes any new fossil-fuel combustion sources.

In this example, there are diesel emissions associated with the collection of manure and support equipment; however, the quantity of diesel fuel combusted is not expected to change by installing a covered lagoon BCS design. This assumption will not be true for all project designs, such as if manure is trucked to a centralized digester. The only new fossil fuel combustion source in this example is a propane pilot light in the IC engine. While the BCS in this example will produce on-site electricity, the applicant must still estimate how the BCS installation will impact electricity usage at the dairy. The applicant in this example estimated an increase in on-site energy demand of 20%. The benefit of the renewable electricity generated from the BCS is calculated separately.

Step 2: Determine the DDRDP GHG Calculator Tool Inputs Needed

Step 2 of this quantification methodology requires applicants to enter project-specific information into the DDRDP Calculator Tool. First, download and open the calculator tool from www.arb.ca.gov/cci-quantification. The applicant begins by reading the "Read Me" tab and enters project contact information. Next, the applicant will click on the "Project Data Inputs" tab and enter required project information.

Below are a series of screenshots of the "Project Data Inputs" tab of the DDRDP GHG Calculator Tool. The fields highlighted yellow are required for all projects, while the fields highlighted green may apply to some projects. Where input fields do not apply to the applicants project, they may be left blank or a "0" value may be input.

The project description entry fields identify the type of BCS, biogas destruction device, solid separation system, project location, presence of an uncovered effluent pond, DDRDP and total GGRF funds requested, and milk production characteristics. Options are selected from drop-down lists, or input by the applicant, depending on the field.

If there is more than one biogas destruction device, the applicant will select both a primary and a secondary on this screen, and input the % of biogas expected to be destroyed by each device. If there is only one, as in this example, the applicant will enter 100% for the primary biogas destruction device. If one of the destruction devices is a boiler, the applicant will need to complete an additional "Boiler Worksheet" tab.

Input Proposed Project Information

Biogas Control System (BCS)	Covered Lagoon
Primary Biogas Destruction Device	Rich-burn Internal Combustion Engine
Secondary Biogas Destruction Device	
Baseline Solid Separation	Stationary Screen
BCS Solid Separation	Stationary Screen
Uncovered Effluent Pond?*	Yes
Project Location (county)	Kern
DDRDP GGRF $ Requested	$2,000,000.00
Total GGRF $ Requested	$2,000,000.00
Milk Fat (%)	3.75%
Milk true Protein (%)	3.00%
Milk Lactose (%)	4.90%
Milk Produced (kg/cow/day)	25
ECM (kg/cow/day)	24.66
10 yr ECM (mt)	180,026

100%	% Biogas to be destroyed in primary destruction device (over 10 years)
	% Biogas to be destroyed in secondary destruction device (over 10 years)

Applicants next enter data for the current practices (baseline scenario). For input 1, applicants enter the number of livestock by category. In this example, all the lactating dairy cows are housed in freestalls, so nothing is entered for "Dairy Cows (open lot corrals)."

For input 2, applicants identify the % of volatile solids deposited on land and not collected. Default values are provided, and are used in this example.

For input 3, applicants indicate the % of volatile solids separated prior to entry into the anaerobic lagoon and sent to any other treatment or storage system or end use. The tool automatically provides a default % of volatile solids separated and sent to an alternative storage/treatment system based on the solid separation technology identified by the applicant. In this example, equal portions of separated solids are sent to two different practices. To account for this, the applicant will enter half of the default value in input 3 and select "dried for bedding" and the other half in input 4 and select "daily spread."

For Input 5, applicants enter the fraction of volatile solids that enter the anaerobic lagoon. If all volatile solids that do not enter the lagoon are accounted for in inputs 2-4, then the applicant will enter the 100% minus the values input in 2-4, so that all values should sum to 100%.

Finally, the applicant will input baseline energy consumption by fuel type.

Baseline Manure Management -- Enter data regarding management practices using averages of preceding 12 months

	1. Enter number of livestock by category	2. Enter % of manure volatile solids (VS) deposited on land and not collected — Default		3. Enter % VS from solid separation prior to lagoon sent to other treatment/storage practice — Default		4. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	5. Enter % VS entering anaerobic storage/treatment system (lagoon) by livestock category	Total Volatile Solids must sum to 100%
Dairy Cows (freestall)	2,000	20%	20%	14%	14.0%		66.0%	100%
Dairy Cows (open lot corrals)		70%		17%				
Dry cows	200	70%	70%	5%	2.5%	2.5%	25.0%	100%
Heifers	300	70%	70%	5%	2.5%	2.5%	25.0%	100%
			Pasture / Dirt		Dried for bedding / Composting intensive windrow	Daily Spread		
					Identify current practice for separated solids	Identify other current treatment/storage practice		

Energy Use Associated with Current Waste Management Practices

Electricity Consumed	MWh/yr	500
Fuel Consumed	Diesel (Distillate No. 1 or 2, gal.)	500
Fuel Consumed		
Fuel Consumed		

*Select Applicable Fuel(s) from List.

Just as with the baseline scenario, applicants next enter information for the project scenario describing planned conditions and practices after the installation of a biogas control system. For all projects, the livestock population is assumed to remain constant over the life of the project. In this example, practices regarding solid separation are not expected to change as a result of the project, so the inputs 6-9 are identical to those in the baseline scenario. If changes were planned – such as, for example, processing a higher percentage of manure solids in a continuous stirred tank reactor – applicants would indicate such changes in this section. In this example, the electricity consumption is expected to increase, and a new source (propane) has been included.

A table to list relevant CO_2 emission sources is located at the bottom of the screen. This is intended to be a descriptive list to provide supplemental information, and is not used directly in the emissions calculations. In the DDRDP GHG Calculator Tool, emission sources are aggregated by fuel-type for the purposes of calculations (e.g. diesel, natural gas, propane, etc.), but individual sources must still be listed at the bottom to identify what sources combusted each of the fuels identified. In this table, applicants also identify from a drop-down list whether each source is a new source (after installation of the BCS), or whether there is expected to be an increase, decrease or no change in fuel consumption and GHG emissions as a result of installing the BCS.

Project Manure Management -- Estimate Data Regarding Management Practices after Installation of BCS

	Number of Livestock by Category	6. Enter % of manure volatile solids (VS) deposited on land and not collected		7. Enter % VS from solid separation prior to BCS sent to other treatment/storage practice		8. (if applicable) Enter % VS sent to any other non-anaerobic treatment/storage	9. Enter % VS sent to (managed in) biogas control system by livestock category	Total Volatile Solids
		Default		Default				must sum to 100%
Dairy Cows (freestall)	2,000	20%	20%	14%	7.0%	7.0%	66.0%	100%
Dairy Cows (open lot corrals)	0	70%		17%				
Dry Cows	200	70%	70%	5%	2.5%	2.5%	25.0%	100%
Heifers	300	70%	70%	5%	2.5%	2.5%	25.0%	100%
			Pasture / Dirt		Dried for bedding / Composting intensive windrow	Daily Spread		
					Identify Post-Project Practice for Separated Solids	Identify Other Post-Project Practice		

Projected Energy Usage after Installation of Biogas Control System

Electricity Consumed	MWh/yr	600
Fuel Consumed	Diesel (Distillate No. 1 or 2, gal.)	500
Fuel Consumed	Propane / LPG (gallons)	30
Fuel Consumed		

*Select Applicable Fuel(s) from List.

Description of Stationary and Mobile Sources associated with Manure Management Activities included in GHG Emission Calculations

Source Description	Fuel Type	Change in emissions relative to Baseline
Manure collection support equipment	Diesel (Distillate No. 1 or 2, gal.)	No Change
Pilot light in IC engine	Propane / LPG (gallons)	New Source

Step 3: Estimate Net GHG Emission Reductions Calculated using the DDRDP GHG Calculator Tool

After inputting all the required data, the applicant will click on the “GHG Summary” tab of the worksheet. The “GHG Summary” tab displays the results calculated by the DDRDP GHG Calculator Tool.

The first four dark gray rows contain the metrics required to be reported by the project applicant. In this example, baseline GHG emissions were calculated to be 10,495 metric tons CO_2e/yr.[3] After installation of the BCS, GHG emissions are expected to be reduced to 2,048 mtCO_2e/yr. There is also an additional benefit of avoiding 442 mtCO_2e/yr through the generation of electricity. This results in a net GHG reduction of 9,163 mtCO_2e/yr. Over the life of the project, this yields a total estimated net GHG reduction of 91,643 mtCO_2e.

The total GHG emission reduction divided by the calculated energy corrected milk production rate yields 0.51 mtCO_2e / mtECM. For this project, both the DDRDP GGRF and total GGRF funds requested are the same, with 0.046 mtCO_2e reduced per dollar of GGRF requested.

Total Project Emission Reductions over 10 years	**Total Estimated Project GHG Reductions**	**91,634**	**mtCO2e**
GHG reduction per unit energy-corrected milk over 10 years	**GHG/ECM**	**0.51**	**mtCO2e/ mt ECM**
GHG reduction per $ DDRDP GGRF grant money requested over 10 years	**GHG/(DDRDP GGRF $)**	**0.046**	**mtCO2e/$ requested**
GHG reduction per $ Total GGRF grant money requested over 10 years	**GHG/(Total GGRF $)**	**0.046**	**mtCO2e/$ requested**
Baseline CH4 emissions from anaerobic storage/treatment systems	BE_CH4 AS	10,494.75	mtCO2e/yr
Baseline CH4 emissions from non-anaerobic storage/treatment systems (including separated solids)	BE_CH4 NAS	117.73	mtCO2e/yr
Baseline CO2 emissions associated with current manure mgmt practices	BE_CO2 other	156.97	mtCO2e/yr
Total Annual Baseline Emissions	**BE_Total**	**10,769**	**mtCO2e/yr**
Project CH4 emissions from biogas collection and destruction inefficiencies	PE_CH4 BCDE	604.83	mtCO2e/yr
Project CH4 emissions from effluent pond	PE_CH4 EP	1,138.09	mtCO2e/yr
Project CH4 emissions from non-anaerobic storage/treatment systems (including separated solids)	PE_CH4 NAS	117.73	mtCO2e/yr
Project CO2 emissions associated with manure mgmt practices after installation of BCS	PE_CO2	187.44	mtCO2e/yr
Total Annual Project Emissions	**PE_Total**	**2,048**	**mtCO2e/yr**
Total Annual Direct Emission Reductions	**DER_Total**	**8,721**	**mtCO2e/yr**
Avoided CO2 emissions from upgrade to biomethane (if applicable)	AD_CO2	0.00	mtCO2e/yr
Avoided CO2 emissions from boiler thermal energy use (if applicable)	ANG_CO2	0.00	mtCO2e/yr
Avoided CO2 emissions from electricity generation (if applicable)	AEG_CO2	442.00	mtCO2e/yr
Total Annual Project Emission Reductions	**Project Annual Total**	**9,163**	**mtCO2e/yr**

[3] “Carbon dioxide equivalent” or “CO2e” means the number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas. "Global warming potential" or "GWP" means the ratio of the time-integrated radiative forcing from the instantaneous release of one kilogram of a trace substance relative to that of one kilogram of a reference gas, i.e., CO2. “Metric tons” are abbreviated as “mt” rather than “MT” in this quantification methodology to be consistent with the Livestock Protocol (ARB 2014).

Appendix B. Equations Supporting the DDRDP GHG Calculator Tool

Methods used in the DDRDP GHG Calculator Tool for estimating the net GHG emission reductions by activity type are provided in this appendix. The GHG emission reductions from the project are quantified within the DDRDP GHG Calculator Tool using the equations below.

The GHG emission reductions from DDRDP projects is calculated using Equation 13 as the difference between the baseline and project scenarios plus the additional GHG benefit of electricity generation, avoided diesel emissions from the use of biomethane as a transportation fuel or avoided natural gas emissions from the recovery and use of thermal energy from a boiler.

A. Calculation of annual baseline methane emissions

Baseline scenario methane emissions represent the emissions within the Project Boundary that would have occurred without the installation of the BCS. Applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors. Baseline emissions must be calculated according to the manure management system in place prior to installing the BCS.

The procedure to determine the project baseline methane emissions uses Equations 1, 2 and 3, with Equations 2 and 3 as inputs to Equation 1. Equation 2 calculates CH_4 emissions from anaerobic manure storage/treatment systems (e.g. anaerobic lagoons, storage ponds, etc.) based on project-specific mass of volatile solids degraded by the anaerobic storage/treatment system and available for methane conversion. The equation incorporates the effects of temperature and accounts for the retention of volatile solids. Equation 3 applies to predominately non-anaerobic storage/treatment systems and is used to calculate emissions from separated solids and other volatile solids not sent to an anaerobic lagoon or storage pond. Both Equations 2 and 3 reflect basic biological principles of methane production from available volatile solids, determine methane generation for each livestock category, and account for the extent to which the waste management system manages each category's manure. The calculation procedure uses a combination of project-specific variables and default factors:

Population – P_L

The procedure for establishing population values requires the applicant to differentiate between livestock categories ('L') such as lactating dairy cows, dry cows (non-milking dairy cows), heifers, etc., to account for differences in methane generation across livestock categories. The population of each livestock category is monitored on a monthly basis and averaged for an annual total population for the previous 12 months. Factors that are specific to livestock categories are described below, denoted with "L" and covered in Tables C.2 and C.3.

Volatile Solids – VS_L
This value represents the daily organic material in the manure for each livestock category and consists of both biodegradable and non-biodegradable fractions. The VS content of manure is a combination of excreted fecal material (the fraction of a livestock category's diet consumed and not digested) and urinary excretions, expressed in a dry matter weight basis (kg/animal).

Average Weight – $Mass_L$
This value is the annual average live weight of the animals, per livestock category. Typical Average Mass (TAM) values should be used (Table C.2).

Maximum Methane Production – $B_{0,L}$
This value represents the maximum methane-producing capacity of the manure, differentiated by livestock category ('L') and diet. Default $B_{0,L}$ factors from Table C.3 must be used.

Manure Management System – MS
The MS value apportions volatile solids from each livestock category to an appropriate manure management system component ('S'). The MS value accounts for the operation's multiple types of manure management systems and is expressed as a percent (%), relative to the total amount of volatile solids produced by the livestock category. As waste production is normalized for each livestock category, the percentage should be calculated as percent of population for each livestock category. For example, a dairy operation might send 85% of its milking cows' waste to an anaerobic lagoon and 15% could be deposited in a corral. In this example, an MS value of 85% would be assigned to Equation 2 and 15% to Equation 3.

The MS value also accounts for the fraction of volatile solids separated through a solid separation technology. Site-specific data should be used if available. If site-specific data is unavailable, default values from table C.8 are used to calculate an MS value for separated solids.

Methane Conversion Factor – MCF
Each manure management system component has a volatile solids-to-methane conversion efficiency, which represents the degree to which maximum methane production (B_0) can be achieved. Default MCF values for non-anaerobic manure storage/treatment are available in Table C.4, which are used for Equation 3.

Equation 1: Baseline Methane Emissions

$$BE_{CH4} = BE_{CH4,AS} + BE_{CH4,non-AS}$$

Where,			Units
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic storage/treatment systems	$mtCO_2e/yr$
$BE_{CH4,non-AS}$	=	Total annual project baseline methane emissions from predominately non-anaerobic storage/treatment systems	$mtCO_2e/yr$

Equation 2: Baseline Methane Emissions from Anaerobic Storage / Treatment

$$BE_{CH4,AS} = \sum_{l,i} (VS_{\deg AS,l,i} \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$mtCO_2e/yr$
$VS_{degAS,L,i}$	=	Monthly volatile solids degraded in anaerobic manure storage/treatment system 'AS' from livestock category 'L' in month 'i'	kg dry matter
$B_{0,L}$	=	Maximum methane producing capacity of manure for livestock category 'L' from Table C.3	m^3 CH_4/kg of VS
0.68	=	Density of methane (1 atm, 60^oF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential of methane[vi]	

With:

$$VS_{\deg,AS,L,i} = f_i \times VS_{avail,AS,L,i}$$

Where,			Units
$VS_{deg,AS,L,i}$	=	Volatile solids degraded by anaerobic manure storage/ treatment system 'AS' by livestock category 'L' in month "i"	kg dry matter
$VS_{avail,AS,L,i}$	=	Monthly volatile solids available for degradation from anaerobic manure storage/treatment system 'AS' by livestock category 'L'	kg dry matter
f_i	=	The van't Hoff-Arrhenius factor = "the proportion of volatile solids that are biologically available for conversion to methane based on the monthly average temperature of the system"	

With:

$$f_i = MIN\left(\exp\left[\frac{E(T_2 - T_1)}{RT_1T_2} \right], 0.95 \right)$$

Where,			Units
f	=	The van't Hoff-Arrhenius factor for month "i"	
E	=	Activation energy constant (15,175)	cal/mol
T_1	=	303.16	Kelvin
T_2	=	Monthly average ambient temperature (K = °C + 273). If T_2 < 5 °C then f = 0.104[vii]	Kelvin
R	=	Ideal gas constant (1.987)	cal/Kmol

Equation 2: Baseline Methane Emissions from Anaerobic Storage / Treatment Systems (continued)

And:

$$VS_{avail,AS,L,i} = \left(VS_L \times P_L \times MS_{AS,L} \times dpm_i \times 0.8\right) + \left(VS_{avail,AS,L,i-1} - VS_{\deg,AS,L,i-1}\right)$$

Where,

			Units
$VS_{avail,AS,L,i}$	=	Volatile solids available for degradation in anaerobic storage/treatment system 'AS' by livestock category 'L' in month 'i'	kg dry matter
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis.	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{AS,L}$	=	Fraction of volatile solids sent to (managed in) anaerobic manure storage/treatment system 'AS' from livestock category 'L'	%
dpm_i		Days per month 'i'	days
0.8	=	System calibration factor	
$VS_{avail,AS,L,i-1}$	=	Previous month's volatile solids available for degradation in anaerobic system 'AS'	kg
$VS_{deg,AS,L,i-1}$	=	Previous month's volatile solids degraded by anaerobic system 'AS'	kg

With:

$$VS_L = VS_{table} \times \frac{Mass_L}{1000}$$

Where,

VS_L	=	Volatile solid excretion on a dry matter weight basis	kg/ animal/ day
VS_{table}	=	Volatile solid excretion from Table C.3	kg/ day/ 1000kg
$Mass_L$	=	Average live weight for livestock category 'L' from Table C.2	

Equation 3: Baseline Methane for Non-Anaerobic Storage/Treatment Systems

$$BE_{CH4,non-AS} = \sum_{s,l} (P_l \times MS_{non-AS,s,l} \times VS_l \times 365.25 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$BE_{CH4,non-AS}$	=	Total annual baseline methane emissions from non-anaerobic storage/treatment systems	$mtCO_2e$
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{non-AS,s,L}$	=	Fraction of volatile solids from livestock category 'L' managed in non-anaerobic storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's' from Table C.5.	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L' from Table C.3	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60^oF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	
S	=	Manure treatment/storage system, see Table C.5.	

B. Estimation of Project Methane Emissions

Even after installation of a BCS, some methane will still be emitted to the atmosphere through biogas collection and destruction inefficiencies and periods of equipment malfunction. This quantification methodology includes an estimate of methane released to the atmosphere through biogas collection and destruction inefficiencies using Equation 4.

For projects where BCS design includes an uncovered effluent pond, project methane emissions from residual volatile solids in the effluent pond(s) must be calculated using Equation 5. If a project design does not include an effluent pond, or if the effluent pond is covered and methane from the effluent pond is recovered as part of the BCS design, these emissions are omitted from project calculations.

Applicants must also calculate CH_4 emissions from any volatile solids sent to other waste management and storage systems after the installation of a BCS (including but not limited to separated solids) using Equation 6.

Total project methane emissions after installation of a BCS are summed in Equation 7.

Equation 4: Estimated Annual Methane Emissions from the BCS

$$PE_{CH4,\ BCDE} = BE_{CH4,\ AS} \times [(1/BCE) - BDE]$$

Where,			Units
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$mtCO_2e/yr$
$BE_{CH4,AS}$	=	Total annual project baseline methane emissions from anaerobic manure storage/treatment systems	$mtCO_2e/yr$
BCE	=	Biogas collection efficiency from Table C.4.	fraction (0-1)
BDE	=	Biogas destruction efficiency from Table C.7.	fraction (0-1)

Equation 5: Estimated Project Methane Emissions from the BCS Effluent Pond(s)

$$PE_{CH4,EP} = VS_{EP} \times 365 \times MCF_{EP} \times 0.68 \times 0.001 \times 25$$

Where,			Units
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$mtCO_2e$
VS_{EP}	=	Volatile solids to effluent pond	Kg/day
365.25	=	Days in a year	days
MCF_{EP}	=	Methane conversion factor for liquid/slurry from Table C.5.	%
0.68	=	Density of methane (1 atm, 60^oF)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	

with:

$$VS_{EP} = \sum_l (VS_l \times P_l \times B_{0,l} \times MS_{l,BCS}) \times 0.3$$

Where,			Units
VS_{EP}	=	Volatile solids to effluent pond	Kg/day
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L' from Table C.3	m^3 CH_4/kg of VS dry matter
$MS_{L,BCS}$	=	Percent of manure from livestock category 'L' managed in the BCS	%
0.3	=	Default value representing the amount of VS that exits the digester as a percentage of the VS entering the digester	

Equation 6: Estimated Project Methane for Non-Anaerobic Storage/Treatment Systems

$$PE_{CH4,non-BCS} = \sum_{s,l}(P_l \times MS_{non-BCS,s,l} \times VS_l \times 365 \times MCF_s \times B_{0,l}) \times 0.68 \times 0.001 \times 25$$

Where,			Units
$PE_{CH4,non-BCS}$	=	Total annual methane emissions from other waste storage/treatment systems after installation of BCS	$mtCO_2e$
P_L	=	Annual average population of livestock category 'L' (based on monthly population data)	
$MS_{non-BCS,s,L}$	=	Percent of volatile solids from livestock category 'L' managed in non-BCS storage/treatment system 's'	%
VS_L	=	Volatile solids produced by livestock category 'L' on a dry matter basis	kg/ animal/ day
365.25	=	Days in a year	days
MCF_s	=	Methane conversion factor for non-anaerobic storage/treatment system 's' from Table C.5.	%
$B_{0,L}$	=	Maximum methane producing capacity for manure for livestock category 'L' from Table C.3	m^3 CH_4/kg of VS dry matter
0.68	=	Density of methane (1 atm, 60°F)	kg/m^3
0.001	=	Conversion factor from kg to metric tons	
25	=	Global warming potential factor of methane	

Equation 7: Total Project Methane Emissions

$$PE_{CH4} = PE_{CH4,BCDE} + PE_{CH4,EP} + PE_{CH4,non-BCS}$$

Where,			Units
PE_{CH4}	=	Estimated methane emissions after installation of BCS	$mtCO_2e$/yr
$PE_{CH4,BCDE}$	=	Estimated project methane emissions due to methane capture and destruction inefficiencies	$mtCO_2e$/yr
$PE_{CH4,EP}$	=	Methane emissions from the effluent pond after installation of BCS	$mtCO_2e$/yr
$PE_{CH4,non-BCS}$	=	Methane emissions from other waste storage/treatment systems after installation of BCS	$mtCO_2e$/yr

C. Calculation of anthropogenic carbon dioxide emissions and emission reductions associated with the BCS

Carbon dioxide emission sources associated with manure management activities include but are not limited to: electricity use by pumps and equipment, fossil fuel generators used to destroy biogas or power pumping systems or milking parlor equipment; flares; tractors that operate in barns or freestalls; on-site manure hauling trucks; or vehicles that transport manure off-site. For the purposes of calculating baseline CO_2 emissions, applicants should use data from the previous 12 months of dairy operation in addition to the appropriate default factors.

Use Equation 8 to calculate baseline carbon dioxide emissions. Note: Carbon dioxide emissions from the combustion of biogas are considered biogenic emissions and are excluded from the Project Boundary.

Stationary and Mobile Source Emissions: Carbon dioxide emissions associated with manure management activities may decrease, increase or remain unchanged as a result of installing a BCS. Applicants should pay particular attention to any changes in manure collection or transport practices, such as if manure is trucked to a central digester or compost is trucked offsite, and if there are any new fossil fuel combustion sources, such as if natural gas or other fuels are co-fired in an engine or boiler during periods of low biogas production.

Applicants must include a list of all relevant CO_2 emission sources by fuel type. Baseline emissions are calculated based on previous 12-months fuel consumption by fuel type. Project emissions are estimated by the applicant. Applicants must include an explanation of how installation of a BCS will affect fuel consumption by these sources, and estimates for any new sources.

Indirect Electricity Emissions: Projects should include indirect emissions associated with electricity use in the baseline using data from the previous 12 months of dairy operation. Applicants must also estimate annual electricity consumption after the installation of a BCS. In many cases, this is expected to be higher than baseline electricity consumption, as many BCS designs include components (such as tank stirring/mixing) powered by electricity rather than fossil fuels.

When a BCS project includes generation of electricity, avoided fossil CO_2 emissions are calculated and credited using Equation 10. However, even for such projects applicants must *not* input a 0 for electricity consumption in Equation 9, but rather input actual estimated electricity consumption.

Equation 8: Baseline Carbon Dioxide Emissions From Mobile and Stationary Support Equipment, and Electricity Consumption

$$BE_{CO_2} = \left(\sum_c QE_c \times EF_{CO_2,e}\right) + \left[\left(\sum_c QF_c \times EF_{CO_2,f}\right) \times 0.001\right]$$

Where,			<u>Units</u>
BE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption, and mobile and stationary combustion sources	$mtCO_2$
QE_c	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor *e* for electricity used = 0.303[viii]	$mtCO_2$/ MWh
QF_c	=	Quantity of fuel consumed for each mobile and stationary emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f* from Table C.6	kg CO_2/ MMBtu or kg CO_2/gal
c	=	CO_2 emission source	
0.001	=	Conversion factor from kg to metric tons	

Equation 9 is used to calculate Project CO_2 emissions. Any source included in the baseline must be included in the project, unless CO_2 emissions from that source are reasonably expected to be zero after installation of BCS. When applying Equation 9, individual sources may be aggregated by total electricity consumption and by fuel type.

Equation 9: Project Carbon Dioxide Emissions From Mobile and Stationary Equipment, and Electricity Consumption

$$PE_{CO_2} = \left(\sum_c QE_c \times EF_{CO_2,e}\right) + \left[\left(\sum_c QF_c \times EF_{CO_2,f}\right) \times 0.001\right]$$

Where,			<u>Units</u>
PE_{CO2}	=	Anthropogenic carbon dioxide emissions from electricity consumption and mobile and stationary combustion sources	$mtCO_2$
QE_c	=	Quantity of electricity consumed for each emissions source "c"	MWh/yr
$EF_{CO2,e}$	=	CO_2 emission factor *e* for electricity used = 0.303	$mtCO_2$/ MWh
QF_c	=	Quantity of fuel consumed for each mobile and stationary emission source 'c'	MMBtu/yr or gallon/yr
$EF_{CO2,f}$	=	Fuel-specific emission factor *f* from Table C.6	kg CO_2/ MMBtu or kg CO_2/gal
c	=	CO_2 emission source	
0.001	=	Conversion factor from kg to metric tons	

Projects that utilize recovered biogas for electricity generation may calculate the benefit of avoided grid CO_2 emissions using Equation 10. Consistent with other ARB quantification methodologies, a default electrical conversion efficiency 0.3 is assumed for internal combustion engines and turbines.[ix] A default electrical conversion efficiency of 0.45 is assumed for fuel cells.[x] There is also an adjustment factor included to account for expected higher than baseline methane production levels in plug-flow and complete mix/tank digester designs. The adjustment factor is 1.12 for such BCS designs, consistent with assumptions in the UC Davis (2016) *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California* technical report.[xi]

Equation 10: Avoided fossil CO2 emissions associated with use of recovered biogas for electricity generation.

$$AEG_{CO_2} = (BE_{CH4} - PE_{CH4}) \div 25 \times 1000 \times AF \times EC_{CH4} \times NEE \times EEF$$

Where,			Units
AEG_{co2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$mtCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ back to $mtCH_4$)	$mtCO_2e/$ $mtCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
1000	=	Conversion from metric tons to kg	Kg/mt
EC_{CH4}	=	Energy content of methane = 13.89	$kWh/kgCH_4$
NEE	=	Net electrical conversion efficiency. This QM assumes a default value of 0.3 for IC engines and turbines, and 0.45 for fuel cells.	
EEF	=	0.000303 (California electricity grid-average CO_2 emission factor)	$mtCO_2/$ kWh

Projects that upgrade recovered biogas to biomethane for use as transportation fuel, either onsite or through pipeline injection, may calculate the benefit of avoided fossil diesel fuel using Equation 11. This quantification methodology assumes that biomethane used as transportation fuel will avoid diesel truck GHG emissions. An energy balance approach is used, whereby the energy content of recovered CH_4 is assumed to avoid the use of an energy-equivalent quantity of gallons of diesel fuel. A recovery factor of 90% is included to account for the fraction of methane in biogas that is ultimately recovered in upgrading to biomethane, consistent with a UC Davis (2016) report on the evaluation of biogas management technologies.[xii] An adjustment factor is also included to account for greater than baseline methane production levels expected in plug-flow and complete mix/tank digester designs where the BCS is heated above ambient temperatures. The adjustment factor is 1.12 for such BCS designs, consistent with assumptions in the UC Davis (2016) report cited earlier.[xiii]

Equation 11: Avoided diesel carbon dioxide emissions from use of recovered biogas for transportation fuel.

$$AD_{CO_2} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times RF \times EC_{CH4} \div EC_D \times EF_D \times 0.001$$

Where,			Units
AD_{CO2}	=	Avoided diesel fossil CO2 emissions	$mtCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ values calculated previously back to $mtCH_4$)	
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
RF	=	Recovery Factor of 0.9. Assumption that 90% of methane in biogas is ultimately recovered as biomethane.	
EC_{CH4}	=	Energy content of CH_4 = 47.36	MMbtu/mt CH_4
EC_D	=	Energy content of diesel fuel = 0.139	MMBtu/ gallon
EF_D	=	10.194	$kgCO_2$ / gallon
0.001		Conversion factor	mt CO_2 / kg CO_2

Projects that combust biogas in a boiler and utilize recovered thermal energy in non-BCS related processes that reduce demand for fossil-fuel based energy may calculate the benefit of avoided CO_2 emissions using Equation 12. This methodology assumes the reduced thermal energy demand would have been produced by combustion of fossil natural gas in a conventional boiler with comparable efficiency. Hence a stoichiometric approach is valid. An adjustment factor is included to account for expected higher than baseline methane production levels in plug-flow and complete mix/tank digester designs.[xiv]

The utilization factor (UF) in Equation 12 represents the fraction of thermal energy from recovered biogas that is used in processes that replace fossil-based thermal energy. The fraction of thermal energy used to maintain digester temperature or to heat/dry digestate or separated manure solids is excluded from the UF. The UF also excludes the fraction of time when thermal energy produced by the boiler is not used in applicable processes. For example, if thermal energy from the boiler is used only in seasonal winter heating, the UF would not be expected to be more than 25-30%. Likewise, if the boiler operates continuously but recovered thermal energy is used for heating in a process that operates only 12 hours a day, than the UF should not exceed 50%. A maximum UF of 70% is allowed. Applicants who identify boiler as the biogas destruction device will also complete the “Boiler Worksheet” in the DDRDP GHG Calculator tool to assist in the calculation of avoided fossil natural gas emissions.

Equation 12: Avoided fossil natural gas carbon dioxide emissions through use of recovered thermal energy from combustion of biogas in a boiler.

$$ANG_{CO_2} = (BE_{CH4} - PE_{CH4}) \div 25 \times AF \times UF \times 2.74$$

Where,			Units
AEG_{co2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$mtCO_2e/yr$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
25	=	Global warming potential factor of methane. (Dividing by this value converts $mtCO_2e$ back to $mtCH_4$)	$mtCO_2e/$ $mtCH_4$
AF	=	Methane production adjustment factor. Use 1 for covered lagoon digester designs and 1.12 for plug-flow and tank/complete mix systems.	
UF	=	Utilization factor. Fraction of thermal energy from boiler used in non-BCS processes that directly reduce fossil natural gas demand.	fraction (0-0.7)
2.74	=	Molecular weight of CO_2 / molecular weight of CH_4.	$mtCO_2$ / $mtCH_4$

D. Calculation of the net GHG emission reduction attributable to the project

GHG emission reductions from a DDRDP project are quantified by summing the baseline methane and anthropogenic carbon dioxide emissions, subtracting from this any remaining project emissions, and adding to this the avoided carbon dioxide emissions from the utilization of recovered biogas using Equation 13. Emission reductions are aggregated over a 10 year period, the minimum project life-time.

Equation 13: Project GHG Emission Reductions from Installing a BCS

$$ER = (BE_{CH4} + BE_{CO2} - PE_{CH4} - PE_{CO2} + AD_{CO_2} + ANG_{CO_2} + AEG_{CO_2}) \times 10$$

Where,			Units
ER	=	Calculated net GHG emission reduction over 10 years	$mtCO_2e$
BE_{CH4}	=	Total annual project baseline methane emissions	$mtCO_2e/yr$
BE_{CO2}	=	Baseline carbon dioxide emissions associated with manure management from stationary and mobile sources	$mtCO_2e/yr$
PE_{CH4}	=	Estimated residual methane emissions after installation of BCS	$mtCO_2e/yr$
PE_{CO2}	=	Estimated carbon dioxide emissions associated with manure management from stationary and mobile sources after instillation of BCS	$mtCO_2e/yr$
AD_{CO2}	=	Avoided diesel fossil CO2 emissions	$mtCO_2e/yr$
ANG_{CO2}	=	Avoided natural gas fossil CO2 emissions	$mtCO_2e/yr$
AEG_{CO2}	=	Avoided fossil CO_2 emissions associated with electricity generation	$mtCO_2e/yr$
10	=	Minimum project lifetime	years

E. Calculation of Other Reported Metrics

In addition to a calculation of the total GHG emission reductions over 10 years, the DDRDP GHG Calculator Tool also computes the following metrics:

- GHG reduction per unit energy-corrected milk produced by operation; and
- GHG reduction per $ GGRF grant money invested.

The calculation of GHG reduction per unit energy-corrected milk uses the energy corrected milk production calculated using Equation 14:

Equation 14: Energy-Corrected Milk (ECM)

$$ECM = \frac{(\text{Fat} \times 41.65) + (\text{Protein} \times 24.13) + (\text{Lactose} \times 21.60) - 11.72}{1000} \times \frac{2.204 \times \text{Milk}}{0.721}$$

Where,			<u>Units</u>
ECM	=	Energy-Corrected Milk	kg/cow/d
Fat	=	Milk fat %	%
41.65	=	Energetic value for fat	
Protein	=	Milk true protein %	%
24.13	=	Energetic value for protein	
Lactose	=	Milk lactose %	%
21.60	=	Energetic value for lactose	
Milk	=	Milk produced	kg/d
0.721	=	Energy value of 1 kg of standard milk (standard milk is defined for this program as 3.75% fat, 3.0% true protein and 4.9% lactose).	Mcal/kg

Project applicants must use dairy-specific values for fat, true protein, and lactose characteristics when available. If unavailable, the default values for standard milk may be used.

Appendix C. Emission Factor Tables

All emission factors and tables in Appendix C are derived from the ARB Livestock Protocol (2014).[xv] In Table C.6, several emission factors have been averaged or omitted (where unlikely to be used at dairies) to simply reporting for applicants.

Table C.1. Definitions of Manure Management System Components

System	Definition
Pasture/Range Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread Paddock	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO2 and CH4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting – In-vessel*	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting – Static pile*	Composting in piles with forced aeration but no mixing.
Composting – Intensive windrow*	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting – Passive windrow*	Composting in windrows with infrequent turning for mixing and aeration.
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.

*Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Table C.2. Livestock Categories and Typical Average Mass ($Mass_L$)

Livestock Category (L)	Livestock Typical Average Mass (TAM) in kg
Dairy cows	680
Dry cows	684
Heifers	407

Table C.3. Volatile Solids and Maximum Methane Potential by Livestock Category

Livestock category (L)	VS_{Table} (kg/day/1,000 kg mass)	$B_{o,L}$ (m^3 CH_4/kg VS added)
Dairy cows	11.41	0.24
Dry cows	5.56	0.24
Heifers	8.44	0.17

Table C.4. Biogas Collection Efficiency by Digester Type

Digester Type	Cover Type	Biogas Collection Efficiency (BCE)
Covered Anaerobic Lagoon	Bank-to-bank, impermeable	0.95
	Partial area (modular), impermeable	0.95 x % area covered
Complete mix, plug flow, or fixed film digester	Enclosed vessel	0.98

Table C.5. IPCC 2006 Methane Conversion Factors by Manure Management System Component/Methane Source ‘S’

MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS																					
System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Pasture/Range/ Paddock		1.0%					1.5%											2.0%			Judgment of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Daily spread		0.1%					0.5%											1.0%			Hashimoto and Steed (1993).
Solid storage		2.0%					4.0%											5.0%			Judgment of IPCC Expert Group in combination with Amon et al. (2001), which shows emissions of approximately 2% in winter and 4% in summer. Warm climate is based on judgment of IPCC Expert Group and Amon et al. (1998).
Dry lot		1.0%					1.5%											2.0%			Judgment of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Liquid / Slurry	With natural crust cover	10 %	11 %	13 %	14 %	15 %	17 %	18 %	20 %	22 %	24 %	26 %	29 %	31 %	34 %	37 %	41 %	44 %	48 %	50 %	Judgment of IPCC Expert Group in combination with Mangino et al. (2001) and Sommer (2000). The estimated reduction due to the crust cover (40%) is an annual average value based on a limited data set and can be highly variable dependent on temperature, rainfall, and composition. When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.
	W/out natural crust cover	17 %	19 %	20 %	22 %	25 %	27 %	29 %	32 %	35 %	39 %	42 %	46 %	50 %	55 %	60 %	65 %	71 %	78 %	80 %	Judgment of IPCC Expert Group in combination with Mangino et al. (2001). When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.

a Definitions for manure management systems are provided in Table C.1.

Table C.5. Continued

MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS																				
System[a]		MCFs by average annual temperature (°C)																		Source and comments
		Cool					Temperate										Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Uncovered anaerobic lagoon		66%	68%	70%	71%	73%	74%	75%	76%	77%	77%	78%	78%	78%	79%	79%	79%	79%	80%	80%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001). Uncovered lagoon MCFs vary based on several factors, including temperature, retention time, and loss of volatile solids from the system (through removal of lagoon effluent and/or solids).
Pit storage below animal confinements	< 1 month	3%					3%										3%				Judgment of IPCC Expert Group in combination with Moller et al. (2004) and Zeeman (1994). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.
	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Equation 7.

a Definitions for manure management systems are provided in Table C.1.

Table C.5. Continued

MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS																					
System[a]		**MCFs by average annual temperature (°C)**																			**Source and comments**
		Cool					**Temperate**											**Warm**			
		≤ 10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**≥ 28**	
Anaerobic digester		0-100%					0-100%											0-100%			Should be subdivided in different categories, considering amount of recovery of the biogas, flaring of the biogas and storage after digestion.
Burned for fuel		10%					10%											10%			Judgment of IPCC Expert Group in combination with Safley et al. (1992).
Cattle and Swine deep bedding	< 1 month	3%					3%											30%			Judgment of IPCC Expert Group in combination with Moller et al. (2004). Expect emissions to be similar, and possibly greater, than pit storage, depending on organic content and moisture content.
Cattle and Swine deep bedding (cont.)	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	90%	Judgment of IPCC Expert Group in combination with Mangino et al. (2001).
Composting - In-vessel[b]		0.5%					0.5%											0.5%			Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are less than half of solid storage. Not temperature dependent.
Composting - Static pile[b]		0.5%					0.5%											0.5%			Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are less than half of solid storage. Not temperature dependent.

a Definitions for manure management systems are provided in Table C.1.
b Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Table C.5. Continued

Composting - Intensive windrow[b]	0.5%	1.0%	1.5%	Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are slightly less than solid storage. Less temperature dependent.
Composting – Passive windrow[b]	0.5%	1.0%	1.5%	Judgment of IPCC Expert Group and Amon et al. (1998). MCFs are slightly less than solid storage. Less temperature dependent.
Aerobic treatment	0%	0%	0%	MCFs are near zero. Aerobic treatment can result in the accumulation of sludge which may be treated in other systems. Sludge requires removal and has large VS values. It is important to identify the next management process for the sludge and estimate the emissions from that management process if significant.

b Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Table C.6. CO_2 Emission Factors for Fossil Fuel Use

Fuel Type	Default High Heat Value	Default CO_2 EF	Default CO_2 EF
Natural Gas	**MMBtu / scf**	**kg CO_2 / MMBtu**	**kg CO_2 / scf**
(Weighted U.S. Average)	1.028×10^{-3}	53.02	0.055
Petroleum Products	**MMBtu / gallon**	**kg CO_2 / MMBtu**	**kg CO_2 / gallon**
Diesel (Distillate Fuel Oil No. 1 or 2)	0.139	73.61	10.194
Fuel Oil (Distillate/ Residual Fuel Oil No. 4, 5 or 6)	0.145	74.36	10.810
Kerosene	0.135	75.20	10.152
Liquefied petroleum gases (LPG), including Propane	0.092	62.98	5.794
Motor Gasoline	0.125	70.22	8.778

Table C.7. Biogas Destruction Efficiency Default Values by Destruction Device

Biogas Destruction Device	Biogas Destruction Efficiency (BDE)
Open Flare	0.96
Enclosed Flare	0.995
Lean-burn Internal Combustion Engine	0.936
Rich-burn Internal Combustion Engine	0.995
Boiler	0.98
Microturbine or large gas turbine	0.995
Fuel Cell	0.999
Upgrade and use of gas as CNG/LNG fuel	0.95
Upgrade and injection into natural gas transmission and distribution pipeline	0.98

Table C.8. Volatile Solids Removed Through Solids Separation

Type of Solids Separation	Volatile Solids Removed (fraction)
Gravity	0.45
Mechanical:	
Stationary screen	0.17
Vibrating screen	0.15
Screw press	0.25
Centrifuge	0.50
Roller drum	0.25
Belt press/screen	0.50

[i] As described in Volume 1 of the California Air Resources Board. Funding Guidelines for Agencies Administering California Climate Investments (December 21, 2015) (Funding Guidelines). www.arb.ca.gov/cci-fundingguidelines

[ii] California Air Resources Board. (2014). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems*. https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

[iii] California Air Resources Board. (2011). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems*. https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.

[iv] Greenhouse Gas Quantification Methodology for the California Department of Food and Agriculture Dairy Digester Research and Development Program Greenhouse Gas Reduction Fund Fiscal Year 2014-15. www.arb.ca.gov/cci-quantification.

[v] California Air Resources Board. Funding Guidelines for Agencies Administering California Climate Investments. (December 21, 2015). www.arb.ca.gov/cci-fundingguidelines

[vi] GWP values are taken from the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007). https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html. Note that this is consistent with all other GGRF programs, but differs from the current use in the Livestock Protocol of 21 for the GWP of methane.

[vii] California Climate Data Archive: http://www.calclim.dri.edu/pages/stationmap.html. Applicants should use county-specific defaults provided in the ARB QM Calculator Tool.

[viii] California Air Resources Board. (2016). *Greenhouse Gas Quantification Methodology for the California Department of Community Services and Development Low Income Weatherization Program, Single-Family Energy Efficiency & Solar Photovoltaics, Greenhouse Gas Reduction Fund Fiscal Year 2015-16*. See Appendix A. www.arb.ca.gov/cci-quantification.

[ix] California Air Resources Board. (2016). *Greenhouse Gas Quantification Methodology for the California Department of Resources Recycling and Recovery Waste Diversion Grant and Loan Program, Greenhouse Gas Reduction Fund Fiscal Year 2015-16*. www.arb.ca.gov/cci-quantification.

[x] UC Davis Biomass Collaborative, U.S. EPA Region 9, and National Risk Management Research Lab Office of Research and Development. (September 2016). p. 33-34. *Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.* http://biomass.ucdavis.edu/wp-content/uploads/2016/11/EPA600R-16099_BiogasTech_Sept2016.pdf.

[xi] UC Davis California Biomass Collaborative. (2016). *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California: FINAL TECHNICAL REPORT to the State of California Air Resources Board*. Stephen Kaffka, et al. http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf.

[xii] UC Davis Biomass Collaborative, U.S. EPA Region 9, and National Risk Management Research Lab Office of Research and Development. (September 2016). p. 33-34. *Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies.* http://biomass.ucdavis.edu/wp-content/uploads/2016/11/EPA600R-16099_BiogasTech_Sept2016.pdf.

[xiii] UC Davis California Biomass Collaborative. (2016). *Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California: FINAL TECHNICAL REPORT to the State of California Air Resources Board*. Stephen Kaffka, et al. http://biomass.ucdavis.edu/wp-content/uploads/2016/06/ARB-Report-Final-Draft-Transmittal-Feb-26-2016.pdf.

[xiv] ibid.

[xv] California Air Resources Board. (2014). *Compliance Offset Protocol for Livestock Projects: Capturing and Destroying Methane from Manure Management Systems*. https://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm.